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THE INFLUENCE OF WEATHER ON HAWK MOVEMENTS IN COASTAL NORTHERN CALIFORNIA

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ABSTRACT.—Sharp-shinned (*Accipiter striatus*), Cooper's (*A. cooperii*), and Red-tailed (*Buteo jamaicensis*) hawks, and the total species (19) occurring in the Marin Headlands, Marin County, California, were quantified in relation to seven weather variables. Peak counts of raptors occurred in mid- to late September, with counts largely composed of immature hawks. More adult hawks were counted in mid- to late October. Adult and immature Sharp-shinned and Cooper's hawk counts were correlated with days before and after cold fronts, increasing temperature, barometric pressure, wind speed, and decreasing fog cover. Numbers of adult and immature Red-tailed Hawks were correlated negatively with fog and days before cold fronts and positively with temperature and barometric pressure. Cold front presence or absence did not affect Red-tailed Hawk numbers in 1986–1988. Fewer accipiters and Red-tailed Hawks were counted with south winds (headwinds) blowing, and in 1988 more adult birds were counted with north winds (tailwinds). Increasing temperatures, decreasing fog, and an absence of headwinds were correlated the most with counts of all species in the Headlands; cold front presence or absence had no significant influence on numbers in 1986–1988. A decreasing number of days before and after cold fronts was also generally associated with counts. *Received 27 Sept. 1991, accepted 10 Feb. 1992.*

In 1985 the Golden Gate Raptor Observatory (GGRO) was established to monitor fall migration of diurnal raptors over the Marin Headlands, Marin County, California. Binford (1979) first documented large numbers of raptors moving through the headlands in 1972. Raptors heading south are "funneled" through the Marin peninsula by the Pacific Ocean on the west and the extensions of the San Francisco Bay on the east. Consequently, the birds can be counted each fall as they move to the tip of the peninsula and cross the bay. Here, we present the first analysis of weather and hawk data from the headlands site.

In the eastern United States, Europe, and the Middle East, there are many historic migration-viewing sites, from which most of the published literature on weather and hawk migration has come. Although some consistent relationships among weather factors and hawk counts have been found—such as those with wind direction and barometric pressure—much variation remains unexplained. Some variance probably stems from the problems inherent in single-site migration counts, i.e., a limited view of migratory movements (site bias) and a reliance on many different ob-

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servers (a count method bias) (see review in Kerlinger 1989:27,33). Thus, because a substantial proportion of birds is probably not counted (Alerstam 1978), any observed correlations apply only to those observed, and who were reacting to localized and ephemeral weather conditions. However, correlational analyses of local weather and flights are necessary, so that comparisons may be made among different sites and regions. Our objectives were to evaluate the influences of west coast weather on yearly hawk counts, and to compare the findings with those of other migration viewing sites. Because many migration researchers do not examine inter-year differences but instead look for synoptic patterns across multiple years, we assessed within- and between-year correlations of weather and hawk counts to see if there were any patterns. We assessed how 19 species moving through the headlands were affected by weather conditions, but concentrated on how counts of the most abundant migrating species (Cooper's [*Accipiter cooperi*], Sharp-shinned [*A. striatus*], and Red-Tailed [*Buteo jamaicensis*] hawks) were affected, with respect to age and yearly differences, and differential migration patterns.

METHODS

Data collection.—Raptors were counted daily from mid-August to mid-December 1986–1988. Counts were made from the top of Hill 129, a 275 m peak located at the southern tip of the Marin Headlands (37°50′long., 122°30′lat.) that afforded a 360° view of the sky. Volunteer observers (3–8, depending on the time of the season), trained to identify flying raptors, counted hawks each day of the season. At least one volunteer at the site each day was an experienced and adept observer. Observations were made from 09:00–16:00 h, except during days of heavy precipitation, dense fog, or high wind, when the view was obscured. Observers recorded and tracked the hawks as they flew south past Hill 129 and across the San Francisco Bay. Although a great number of birds were observed crossing, some of them undoubtedly doubled-back. This may have occurred especially during more inclement weather, when they might have been unwilling or unable to cross the Bay (Mueller and Berger 1967). In light of this, hawks were watched for as long as possible to reduce double-counting (Kerlinger 1989), but it is likely that a small (and unknown) percentage of our data reflects hawks counted twice.

Data were recorded on forms adapted from those of the Hawk Migration Association of North America (HMANA). Seven weather variables were chosen for the analyses, based on their associations with bird movements as observed in other studies (e.g., Haugh 1972, Able 1973, Alerstam 1978, Gauthreaux 1980, Titus et al. 1988): surface-level wind direction, wind speed, temperature, fog, barometric pressure, presence or absence of cold fronts, and number of days before and after frontal systems. Wind speeds were taken hourly on the edge of Hill 129 with a hand-held anemometer. Recordings of surface wind direction and temperature also were made hourly. The total number of minutes that observations took place each day was recorded. Fog cover was assessed by Hall from daily field notes that described the length of time Hill 129 and the Marin Headlands were covered. Daily barometric pressure (mm Hg) and presence or absence of frontal systems were obtained from National Oceanic and Atmospheric Administration daily weather maps (1986–1988; 04:00 PST) for the San Francisco Bay area and California. Cold fronts were recorded as "present"

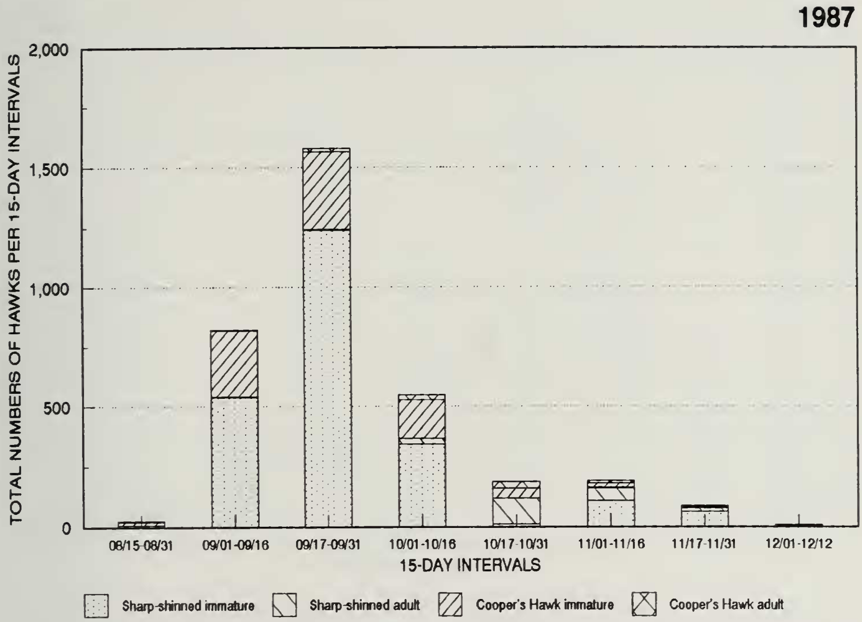

FIG. 1. Total numbers of Sharp-shinned and Cooper's hawks counted at the Marin Headlands, Marin Co., California, 1987, summarized by 15-day intervals.

if they were between 130° longitude and the coast of northern California on the sample day (since this noticeably affected weather conditions in the Headlands) or were determined to have come through the area during the past 24 h.

Analyses.—We analyzed 303 of 355 total sample days from 1986 to 1988. Days with <2 h of observations due to dense fog, rain, and no observations or available cold front information were removed. The resulting numbers of days sampled were: 1986, 98; 1987, 105; and 1988, 100. For 303 days the mean observation hours per day = 5.5 (SD = 1.13).

The numbers of observed hawks were summarized by 15-day intervals for each year, species, and age to provide descriptions of differential migration patterns (Figs. 1–5). As suggested by Richardson (1978), and used by researchers such as Titus and Mosher (1982) and Bednarz et al. (1990), we examined the annual distributions of hawk numbers to see what dates encompassed 95% of the observed migration. We then performed all subsequent analyses on these sample days (Table 1) to represent accurately each species' period of migration.

We analyzed the number of hawks per hour for each sample day for the 19 species counted in the Marin Headlands (total hawks) vs the seven weather variables. Species of hawks observed were: Turkey Vulture (*Cathartes aura*); Black-shouldered Kite (*Elanus caeruleus*); Northern Harrier (*Circus cyaneus*); Sharp-shinned Hawk; Cooper's Hawk; Northern Goshawks (*Accipiter gentilis*); Red-tailed Hawk; Red-shouldered Hawk (*Buteo lineatus*); Swainson's Hawk (*B. swainsoni*); Broad-winged Hawk (*B. platypterus*); Rough-legged Hawk (*B. lagopus*); Ferruginous Hawk (*B. regalis*); Golden Eagle (*Aquila chrysaetos*); Bald Eagle (*Haliaeetus leucocephalus*); Prairie Falcon (*Falco mexicanus*); Peregrine Falcon (*F. peregrinus*); Merlin (*F. columbarius*); American Kestrel (*F. sparverius*); and Osprey (*Pandion haliaetus*).

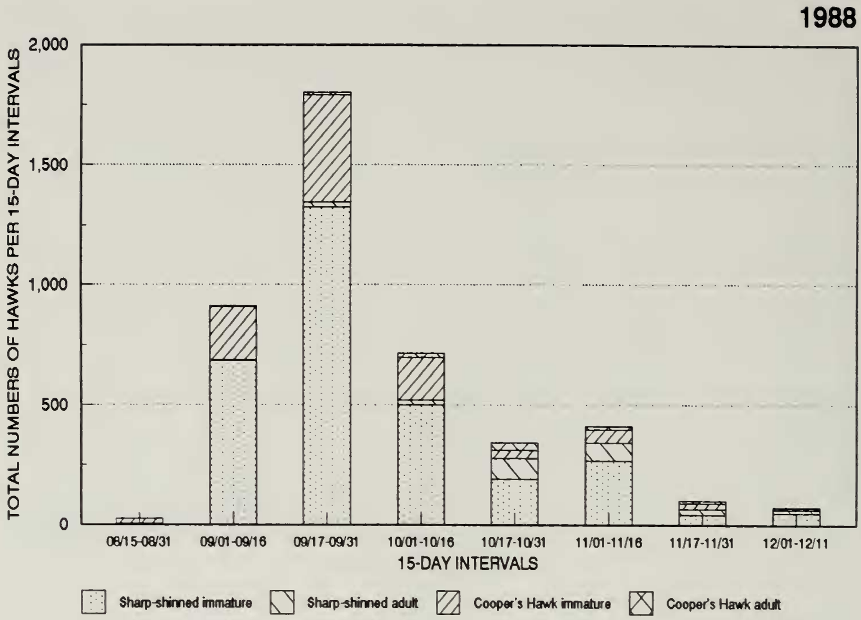

FIG. 2. Total numbers of Sharp-shinned and Cooper's hawks counted at the Marin Headlands, Marin Co., California, 1988, summarized by 15-day intervals.

Numbers of Sharp-shinned, Cooper's, and Red-tailed hawks were also analyzed in relation to the seven weather variables for 1986–1988 and for each year independently. In 1986, Sharp-shinned and Cooper's hawks were counted but not aged, and so we did not conduct analyses on the immature or adult age groups; however, the numbers were included in the total hawk analyses for 1986.

We conducted a Kolmogorov-Smirnoff goodness-of-fit test (two-tailed; Zar 1984:55–58) to see if hawk numbers were normally distributed. Of all the hawk categories, only adult Red-tailed ($P = 0.10$) and immature Sharp-shinned hawk numbers ($P = 0.07$) in 1988 were distributed normally. Therefore, we used Spearman's rank correlations (Zar 1984:318–320) to determine associations of wind directions and cold fronts with hawk numbers. Daily surface wind directions were summarized from hourly recordings, giving a predominant or shifting wind direction for each sample day. The resulting wind directions were combined into six final categories: the four cardinal directions, a no wind category, and a variable winds category (indicating direction shifts during the day). Kruskal-Wallis analysis of variance (K-W ANOVA; Zar 1984:250, and see Haugh 1972 for similar data treatment) was conducted for the three species and for total hawks versus the wind categories. Fog coverage was recorded daily, and for the analyses was converted to codes: 0 = no fog; 1 = up to, but no more than one-half day of fog coverage; and 2 = more than one-half day, but no more than three-quarters of the day under fog. The frequencies of coverage were determined and tested for differences among years (χ^2 analysis with Cramer's phi coefficient [Zar 1984:322]), and the variable was entered into the correlation analysis. Cold fronts were analyzed by Kruskal-Wallis analysis of variance for the number of hawks observed per hour versus the

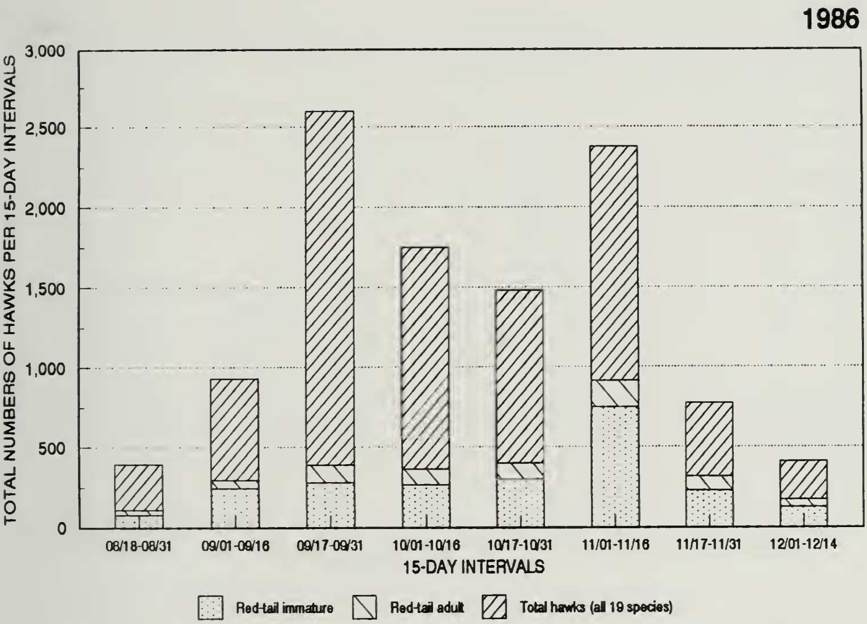

FIG. 3. Total numbers of Red-tailed Hawks and all 19 species of hawks counted at the Marin Headlands, Marin Co., California, 1986, summarized by 15-day intervals.

presence or absence of a cold front. Number of days before and number of days after cold fronts were also included in the Spearman correlation analysis.

We used SPSS-X (SPSS 1988) for all statistical analyses. Barometric pressure, temperature, and wind speed were included in the correlation analysis to see if multicollinearity was high among weather variables (Morrison et al. 1992). Seasonal averages of numbers of hawks, temperatures, barometric pressures, and wind speeds were tested for differences among years by a Kruskal-Wallis ANOVA. All values reported in the text are significant at $P < 0.05$ unless otherwise noted.

RESULTS

Average seasonal temperatures and surface wind speeds differed significantly among years (Table 2), as did percent frequencies of fog cover (Table 3). The 1987 season was the warmest overall and also had the most number of days with westerly winds blowing; the 1986 season had the lowest average wind speeds. North and west winds predominated in the headlands, however, in all three years, variable winds also accounted for a similar proportion of the totals (Table 3). Overall, temperature was negatively correlated with wind speed and fog (i.e., as temperature increased the latter two decreased; $r_s = -0.25$ and -0.30, respectively). Temperature was positively correlated with days before and after cold

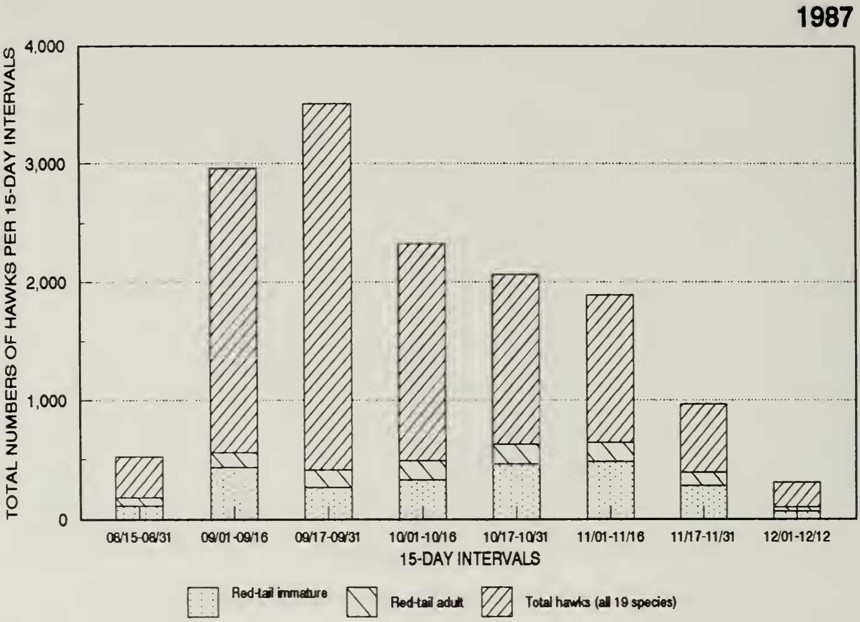

FIG. 4. Total numbers of Red-tailed Hawks and all 19 species of hawks counted at the Marin Headlands, Marin Co., California, 1987, summarized by 15-day intervals.

fronts (indicating that days farther from frontal systems were the warmest; $r_s = 0.23$ and 0.27). Barometric pressure was negatively correlated with fog, wind speed, and days before and after cold fronts ($r_s = -0.12$ to -0.28). Fog was positively associated with days before cold fronts ($r_s = 0.17$). Fronts passed near or through the Marin Headlands on 48 of 303 sample days (Table 3). Days before and after cold fronts were correlated with each other ($r_s = 0.51$).

Total numbers of hawks counted 1986–1988 are summarized in Table 1 for those dates encompassing 95% of the migration seasons in each year. From 1986 to 1988 there were 3490 total Cooper's Hawks counted (aged and unknown-aged hawks combined); 9003 Sharp-shinned Hawks; 10,424 Red-tailed Hawks; and 35,921 hawks of all 19 species together.

Average seasonal numbers of adult Sharp-shinned Hawks per hour were not significantly different between 1987 and 1988. There were no significant differences in mean numbers of adult or immature Cooper's Hawks between 1987 and 1988, or in the numbers of Red-tailed Hawks, for both ages, in 1986–1988. The number of hawks did vary between 1986 and 1988 ($P = 0.03$; Table 4). All species were correlated with each other during the three years (P's < 0.001; r_s's $= 0.25$–0.98).

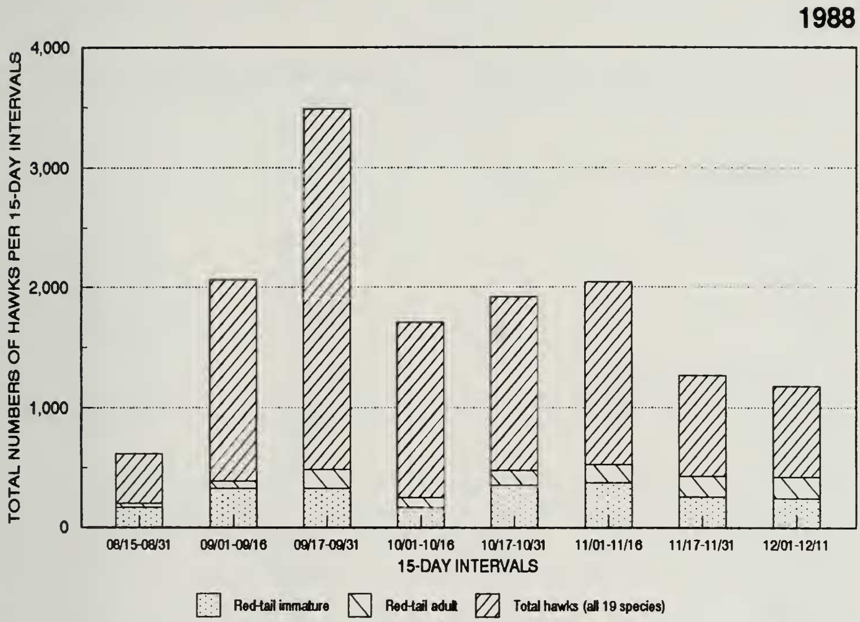

FIG. 5. Total numbers of Red-tailed Hawks and all 19 species of hawks counted at the Marin Headlands, Marin Co., California, 1988, summarized by 15-day intervals.

Peaks in counts of immature Cooper's and Sharp-shinned hawks occurred in mid-September in 1987 and 1988 (Figs. 1 and 2, respectively); adult accipiters were counted mostly in mid-October. Peaks in immature Red-tailed Hawk counts occurred in September and early November 1986–1988; the largest peak in numbers occurred in early November 1986 (Figs. 3–5). Adult Red-tailed Hawks were counted fairly consistently across the seasons, although in early November 1986 there was a small peak in numbers (Figs. 3–5). For all hawk species together, peak counts were in mid- to late September; however, in 1986 there was a second peak in numbers in early November (Figs. 3–5).

Sharp-shinned Hawks.—In 1987, no Spearman rank correlations for adults were significant, but sightings of adults were associated with decreasing fog and wind speed, increasing temperature and pressure, and days before and after fronts (Table 5). In 1988 adults were positively correlated with days after fronts, and in the Kruskal-Wallis ANOVA, tended to be associated with an absence of cold fronts ($P = 0.08$). In 1987, immature birds were negatively correlated with days before and after cold fronts, and they were consistently associated with increasing temperatures and wind speeds (Table 5). They were also observed more on days without

TABLE 1

TOTAL NUMBERS OF HAWKS COUNTED AT THE MARIN HEADLANDS, MARIN COUNTY, CALIFORNIA, IN 1986–1988

Species Age class	Year 1986[a]	1987	1988
Cooper's Hawk			
Adult	–	88	86
Immature	–	837	972
Unknown	904	427	176
Total	904[b]	1352	1234
Sharp-shinned Hawk			
Adult	–	201	242
Immature	–	2306	3057
Unknown	1622	1007	568
Total	1622	3514	3867
Red-tailed Hawk			
Adult	682	938	961
Immature	2238	2309	2207
Unknown	219	543	327
Total	3139	3790	3495
Total hawks (all ages)			
Total	7671	10,918	17,332

[a] Dates used for total numbers represent 95% of all species' migration seasons in each year: 1986, 20 Aug.–14 Dec.; 1987, 20 Aug.–12 Dec.; 1988, 20 Aug.–11 Dec.

[b] Numbers are total numbers of accipiters (adults and immatures together) for 1986, since these hawks were not identified as to age in that year.

cold fronts ($P = 0.02$, K-W ANOVA), and fewer birds were counted when south winds (headwinds) were blowing ($P = 0.04$; Table 6).

Cooper's Hawks.—In 1987, adult accipiter numbers were correlated with a greater number of days before cold fronts (Table 5). They were not counted as much when fronts were present (K-W ANOVA, $P = 0.04$). In 1988, there were no significant correlations, but for both years the counts were associated with decreasing fog, increasing temperatures, and a greater number of days after cold fronts. In 1987 and 1988, immatures were negatively associated with days after cold fronts; in 1987, days before fronts were also negatively correlated with number of immatures (Table 5). Temperature was positively associated with observations of immatures in 1988, and there also was a trend toward counting more immatures with increasing pressure, decreasing fog, and increasing wind speed. In 1987, there tended to be fewer young birds counted with south winds in the Marin Headlands ($P = 0.07$; Table 6); this pattern was significant in 1988 ($P < 0.01$).

TABLE 2

MEAN SEASONAL TEMPERATURES, BAROMETRIC PRESSURES, AND SURFACE WIND SPEEDS AT THE MARIN HEADLANDS, MARIN COUNTY, CALIFORNIA, FROM AUGUST TO DECEMBER, 1986–1988

Variables	1986 $\bar{x}$	1986 SD	1987 $\bar{x}$	1987 SD	1988 $\bar{x}$	1988 SD
	N = 98 days		N = 105		N = 100	
Temperature (°C)	16.4 A[a]	3.52	17.3 AB	3.92	15.9 AC	4.27
Barometric pressure (mmHg)	1017.2 A	3.97	1017.3 A	3.25	1016.9 A	4.93
Surface wind speed (km-h^{-1})	4.0 A	2.50	7.2 B	3.50	7.7 B	3.20

[a] Values with different letters are significantly different among years ($P \leq 0.05$); Kruskal-Wallis analysis of variance.

Red-tailed Hawks.—In 1986–1988, fog and days before cold fronts were consistently negatively correlated with adult hawks, and temperature and pressure were correlated positively with adult hawk counts (Table 5). There were no effects of cold front presence or absence on adult hawk numbers in 1986–1988 (K-W ANOVA, all *P*'s > 0.4). Wind direction was significant only in 1988, when more birds were counted on days with

TABLE 3

PERCENT FREQUENCIES OF FOG, COLD FRONTS, AND SURFACE WIND DIRECTIONS AT THE MARIN HEADLANDS

Variable	Frequency 1986 N = 98 days	1987 N = 105	1988 N = 100
Fog[a]			
0	65	71	68
1	16	11	14
2	15	17	18
Front			
Absent	81	84	86
Present	18	15	14
Surface wind direction			
North	38	22	26
South	7	8	12
East	5	2	0
West	27	37	35
No wind	1	2	0
Variable	21	28	27

[a] See text for explanation.

TABLE 4

MEAN NUMBER OF HAWKS·H^{-1}·DAY^{-1} OBSERVED AT THE MARIN HEADLANDS

Species	1986 $\bar{x}$	1986 SD	1987 $\bar{x}$	1987 SD	1988 $\bar{x}$	1988 SD
	N = 98 days		N = 105		N = 100	
Sharp-shinned Hawk						
Immature	—[a]		3.6	7.17	5.1	7.51
Adult	—		0.3	0.47	0.4	0.72
Cooper's Hawk						
Immature	—		1.3	2.26	1.7	2.62
Adult	—		0.1	2.81	0.2	0.33
Red-tailed Hawk						
Immature	4.1	3.93	3.7	3.46	3.9	3.73
Adult	1.3	1.21	1.5	1.36	1.7	1.53
Total Hawks	13.8	11.92 A	17.3	16.68 AB[b]	19.6	15.81 B

[a] Accipiters were not aged in 1986 and were not included in the analysis.
[b] Values with different letters are significantly different at $P \leq 0.05$, Kruskal-Wallis analysis of variance.

north winds (Table 6). Fog, temperature, and days before cold fronts were significantly correlated with the numbers of immature birds in 1986–1988, and the birds were also consistently associated with rising pressure and fewer days after a front (Table 5). In the Kruskal-Wallis ANOVA, immature Red-tailed Hawks were not associated with the presence or absence of cold fronts (all P's > 0.5). In 1987, there tended to be fewer immatures counted with south winds and more with east winds (P = 0.08), and this pattern was significant in 1986 (P = 0.03) and 1988 (P = 0.01) (Table 6).

Total hawks.—Overall, temperature and fog were most highly correlated with the counts of all species in the Marin Headlands (e.g., highest r's = 0.45 [temperature] and −0.30 [fog]). However, there were also consistent negative correlations with the number of days before a cold front (i.e., more hawks counted closer to a frontal passage). Cold front presence or absence had no significant influences on the total numbers counted in 1986–1988 (all P's > 0.5). Fewer hawks were counted with south and no winds in 1986 (P = 0.05) and 1988 (P = 0.04) (Table 6).

DISCUSSION

Increasing temperatures and decreasing fog influenced the numbers of hawks counted in the Marin Headlands, although the resulting correlations were weak (i.e., no $r_s > 0.51$). Of the 102 correlations of hawk numbers versus weather variables, only 26 were significant. This equates to 28%,

TABLE 5

SIGNIFICANT SPEARMAN RANK CORRELATION COEFFICIENTS, AND NONSIGNIFICANT SIGNS FOR COOPER'S, SHARP-SHINNED, RED-TAILED, AND TOTAL HAWK NUMBERS VS SIX WEATHER VARIABLES

Species		Correlation coefficient (r_s)					
Age	Year	B[b]	F	T	WS	DBF	DAF
Sharp-shinned Hawk							
Adult	1987	+[c]	−	+	−	+	+
	1988	+	−	+	−	+	+0.32[d]
Immature	1987	−	+	+	+	−0.28	−0.43
	1988	−	−	+0.51	+	+	−
Cooper's Hawk							
Adult	1987	−	−	+	+	+0.29	+
	1988	+	−	+	−	−	+
Immature	1987	+	−	+	+	−0.28	−0.42
	1988	+	−	+0.49	+	+	−0.28
Red-tailed Hawk							
Adult	1986	+	−0.30	+	+	−	+
	1987	+	−0.30	+0.22	+	−	−
	1988	+0.48	−0.50	+	−	−0.24	−
Immature	1986	+	−0.22	+0.23	+	−0.25	−
	1987	+	−0.40	+0.27	−	−	−
	1988	+	−0.34	+0.32	−	−0.24	−
Total hawks (all species counted)							
	1986	−	−0.30	+0.35	−	−	+
	1987	−	−0.30	+0.41	+	−	−
	1988	+	−0.29	+0.45	−	−	−

[a] Accipiters were not aged in 1986 and were not included in the analyses.
[b] Variable notation: B = barometric pressure; F = fog; T = temperature; WS = wind speed; DBF = number of days before cold fronts; DAF = number of days after cold fronts.
[c] "+" = positive but nonsignificant correlation; "−" = negative nonsignificant correlation.
[d] All values are significant at $P < 0.05$.

which is not significantly different from what would be expected by random chance (Rohlf and Sokal 1981:156–159). However, the consistent associations with temperature and fog, as well as with wind direction, indicated that these variables did have impact on our counts.

A decreasing number of days before cold fronts was associated with changes in the magnitudes of the Red-tailed and total hawks counted, thus indicating that more birds may have been counted closer to the days that cold fronts passed along the northwest coast. There were notable inter- and intraspecific differences: only counts of Red-tailed Hawks were affected by fog, and more adult Cooper's and Sharp-shinned hawks were

TABLE 6
MEAN RANKS AND P-VALUES FROM A TWO-TAILED KRUSKAL-WALLIS ANALYSIS OF VARIANCE OF HAWKS·H^{-1}·DAY^{-1} VS WIND DIRECTION[a]

Species			Mean rank					
Age	Year	P	North	South	East	West	No wind	Variable wind
Cooper's Hawks								
Adults	1987	0.61	51.8	53.7	72.7	50.0	58.8	46.1
	1988	0.17	48.3	52.2	—[b]	41.6	—	55.8
Immatures	1987	0.07	49.4	28.5	58.3	59.4	39.5	46.6
	1988	0.00	39.5	27.4	—	59.1	—	53.4
Sharp-shinned Hawks								
Adults	1987	0.46	52.9	47.6	65.0	44.0	56.8	56.3
	1988	0.32	55.7	50.6	—	42.6	—	48.1
Immatures	1987	0.14	50.5	26.9	72.3	53.9	45.5	51.6
	1988	0.04	42.0	33.8	—	57.1	—	50.7
Red-tailed Hawks								
Adults	1986	0.37	52.1	36.6	58.2	44.2	8.0	49.3
	1987	0.61	55.6	40.2	72.3	49.4	50.5	49.1
	1988	0.00	66.3	44.3	—	38.2	—	46.4
Immatures	1986	0.03	54.8	25.5	66.4	40.3	24.0	50.8
	1987	0.08	52.0	24.8	72.3	49.7	51.3	56.3
	1988	0.01	56.7	25.0	—	48.4	—	51.5
Total hawks (all species counted)								
	1986	0.05	55.6	32.6	52.0	38.1	11.5	54.1
	1987	0.26	52.1	28.4	66.3	52.8	45.5	52.1
	1988	0.04	49.9	27.4	—	51.3	—	53.4

[a] Accipiters were not aged in 1986 and were not included in the analysis.
[b] During the 1988 season, there were no sample days recorded with east or no winds blowing.

seen on days farther away from cold fronts. Differences in results between hawk ages versus cold front and barometric pressure variables could have been caused by having much smaller sample sizes for adult Cooper's and Sharp-shinned hawks than for immatures.

Our results were comparable to the findings of other researchers. Titus and Mosher (1982), for example, found that increased migration of Sharp-shinned, Red-tailed, and Broad-winged (*B. platypterus*) hawks was correlated with warm temperatures in the eastern United States. Similarly, Millsap and Zook (1988) reported that movements of raptors in Nevada occurred during fair weather in autumn. Studies in other areas of the United States and coastal Europe have demonstrated, however, that large fall movements of birds and raptors primarily are related to low or falling temperatures and rising pressure (e.g., Haugh 1972, Alerstam 1978). This type of weather is excellent for soaring raptors, and commonly occurs after the passage of the cold fronts (Able 1973, Gauthreaux 1980:154, Millsap and Zook 1988), with accompanying favorable winds and rising pressure (Haugh 1972). It is likely that the west coast, in general, experiences warmer temperatures than does the east coast after frontal movements in the fall, leading to the relatively high correlations of hawks with increasing temperatures and pressure.

The influences of cold fronts on hawk migration have been discussed by many researchers (e.g., Mueller and Berger 1961, Heintzelman 1975, Alerstam 1981). Numbers of migrants counted in the east have been seen to increase dramatically after the passage of a front (see Haugh 1972 for review; Able 1973), when inclement weather conditions have subsided. Our data showed that, generally, more hawks were counted closer to the passage of a front, either in the days before or the days after, although adult accipiters seemed to be counted more as the number of days after fronts increased. Increased magnitudes of flight around fronts could have been due to the instability of these low-pressure areas, because the up- and downdraft wind conditions caused by the fronts may have been good for soaring and gliding (Haugh 1972). However, increased counts for some of the birds could also have resulted from the hawks being forced to stopover in the Marin Headlands while the front passed and then to move on in a "wave" after the storm.

Fog strongly influenced Red-tailed Hawk counts. Several explanations for the decreased numbers we saw can be given. First, we may have missed counting a significant proportion of the birds because of reduced visibility. Or, the fog may have deterred migration because of a lack of visual topographical cues (as Binford noted occurring with hawks in the Marin Headlands in 1970–1977 [Macrae 1985]). Or finally, the fog may have made the hawks more sensitive to flying near water, because some land birds are averse to flying over large bodies of water in ephemeral weather conditions (Mueller and Berger 1967; review in Kerlinger 1989). Haugh (1972) likewise found a greater tendency with Red-tailed Hawks in the eastern United States to interrupt their migration when weather conditions deteriorated and to resume flight when conditions again became "stimulatory."

Researchers have intensively studied the relation of wind direction and wind speed to flight (e.g., Evans and Lathbury 1973, Able 1973, Gauthreaux 1980), and the general consensus is that birds migrating south fly significantly more with tailwinds (usually north or northwest winds) than with headwinds (usually south or southeast winds). Our findings for hawks in the Marin Headlands also showed that there were fewer hawks counted when south winds were predominant, and adult Red-tailed Hawks were observed more with north winds. Up to a certain level, increasing wind speed may also facilitate migration (because updrafts are produced, allowing more gliding flight), but beyond this, migration may be impeded (e.g., Alerstam 1978). For the most part, immature accipiters and adult Red-tails were associated with increased surface-level winds at the Marin Headlands, whereas the other hawks reacted variably to wind speeds. Large hawks (with greater wing length : wing breadth ratios) may need faster wind speeds because they need more lift to migrate more efficiently (Pettingill 1970:24). However, our results were too inconclusive to further address this point.

This study has shown that the numbers of hawks counted in the Marin Headlands were influenced by localized, west coast weather patterns. However, the weak correlations also indicated that local weather accounted for only a small portion of the observed variability in the counts. Other factors such as *Zugdisposition* (physiological readiness) and *Zugunruhe* (migratory activity) play significant parts in determining hawk movements in fall, and a factor such as day of the season may also be an important determinant of species' migration, irrespective of weather conditions. Finally, fall migration counts may be especially dependent on the conditions (e.g., weather, foraging) located to the north of the migration study site at a given time, because the local northern situation affects the number of birds migrating south past the study site. However, hawks migrating in fall along the west coast of North America are obviously influenced by the same weather variables that affect birds in eastern North America and Europe, with one difference appearing to be that hawks in the Marin Headlands are counted more when they have warm temperatures and no fog obscuring the San Francisco Bay. These conditions may act to disperse hawks from migration-viewing sites, leading to decreased counts.

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